

# $J/\psi$ production at high $p_T$ in $p + p$ and $A + A$ collisions at STAR

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**Abstract.** The preliminary results of  $J/\psi$  spectra at high transverse momentum ( $5 < p_T < 14$  GeV/c) in  $p + p$  and Cu+Cu collisions at  $\sqrt{s_{NN}} = 200$  GeV are reported. The nuclear modification factor is measured to be  $0.9 \pm 0.2$  at  $p_T > 5$  GeV/c. The correlations between  $J/\psi$  and charged hadrons are also studied in  $p + p$  collisions to understand the  $J/\psi$  production mechanism at high  $p_T$ .

## 1. Introduction

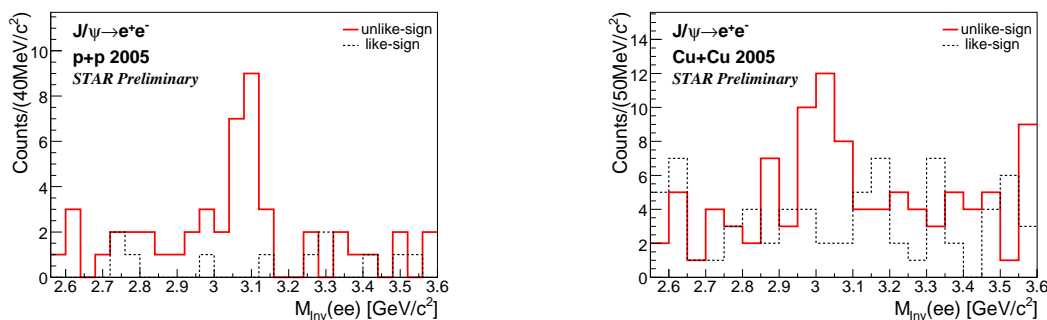
$J/\psi$  dissociation from color-screening of Quantum Chromodynamics (QCD) in a Quark-Gluon Plasma (QGP) is one of the major signatures of QCD de-confinement in relativistic heavy-ion collisions. Recent calculations which assuming the AdS/CFT duality is valid for QCD expect that a heavy fermion pair bound state (an analog of quarkonium in QCD) will have an effective dissociation temperature decreasing with  $p_T$  [1]. This requires a measurement of  $J/\psi$  extending to  $p_T > 5$  GeV/c where the effective  $J/\psi$  dissociation temperature is expected to decrease to the temperature reached at RHIC ( $\sim 1.5 T_c$ ). In this paper, we report the  $J/\psi$  spectra at high transverse momentum ( $5 < p_T < 14$  GeV/c) in  $p + p$  and Cu+Cu collisions at  $\sqrt{s_{NN}} = 200$  GeV. In addition, we performed an analysis of  $J/\psi$ -hadron correlations in  $p + p$  collisions to understand the  $J/\psi$  production mechanism at high  $p_T$ . The technique is similar to that used by UA1 [2] and dihadron correlations analyzed by STAR [3].

UA1 simulated  $J/\psi$ -hadron correlation and found two cases: When a  $J/\psi$  originated from  $\chi_c$  there as no visible near-side correlation, whereas  $J/\psi$ 's originating from  $B$  meson decays showed a strong near-side correlation. The large acceptance of STAR Time Projection Chamber (TPC) [4] and the Barrel Electromagnetic Calorimeter (BEMC) [4] covering  $|\eta| < 1$  are very well suited for such analyzes.

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## 2. Data analysis and Results

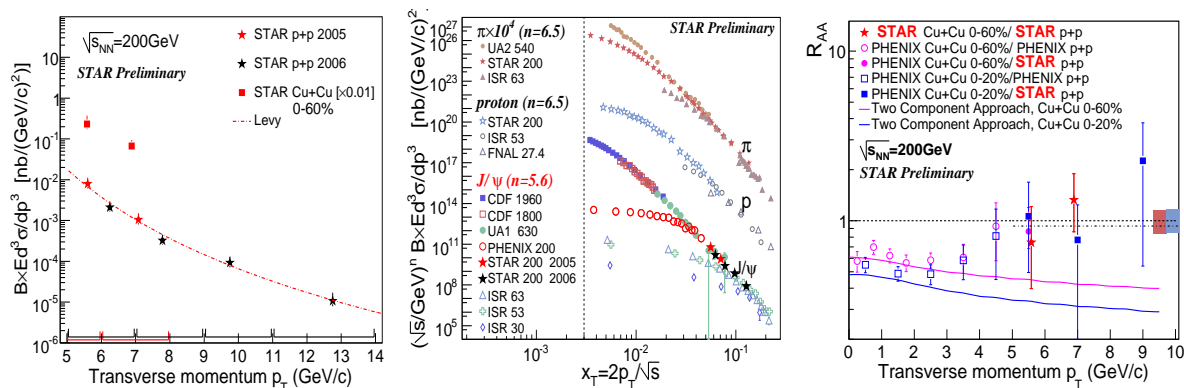
At STAR, both the TPC and BEMC can provide electron identification [4]. At high  $p_T$ , the BEMC is very powerful for electron identification and can also be used to set up a fast trigger to enrich the electron sample. At moderate  $p_T$ , the TPC can identify electrons efficiently. In this analysis, the high  $p_T$   $J/\psi$  was reconstructed through the dielectron channel, one electron at high  $p_T$  identified by combining the BEMC and TPC and the other electron at lower  $p_T$  identified by the TPC only. We used the BEMC triggered data in  $p + p$  and Cu+Cu collisions at  $\sqrt{s_{NN}} = 200$  GeV. The integrated luminosity is  $\sim 2.8$  ( $11.3$ )  $pb^{-1}$  for  $p + p$  collisions collected in year 2005 (2006) with transverse energy threshold  $E_T > 3.5$  (5.4) GeV, and  $\sim 860 \mu b^{-1}$  for Cu+Cu collisions collected in year 2005 with  $E_T > 3.75$  GeV.



**Figure 1.** The dielectron invariant mass distributions in  $p + p$  (left) and Cu+Cu (right) collisions at  $\sqrt{s_{NN}} = 200$  GeV.

Figure 1 shows the high  $p_T$   $J/\psi$  signal in  $p + p$  (left) and Cu+Cu (right) collisions at  $\sqrt{s_{NN}} = 200$  GeV. The background is represented by the dashed lines from like-sign technique. We applied a cut of  $p_T > 2.5 - 4$  GeV/c to the EMC triggered electrons and the cut of  $p_T > 1.2 - 1.5$  GeV/c for lower  $p_T$  electrons. This ensured clean  $J/\psi$  identification. The signal/background (S/B) ratio in the analysis is 22/2 (40/14) in  $p+p$  collisions using year 2005 (2006) data and 17/23 in Cu+Cu collisions. The  $p_T$  coverage in  $p + p$  and Cu+Cu collisions taken in year 2005 is  $5 < p_T < 8$  GeV/c, while in  $p + p$  collisions taken in year 2006, the  $J/\psi$   $p_T$  can reach 14 GeV/c due to higher recorded luminosity and full BEMC coverage. The  $J/\psi$  invariant cross section  $B_{ee} \times Ed^3\sigma/dp^3$ , after efficiency correction, are shown as symbols in Figure 2 (left).

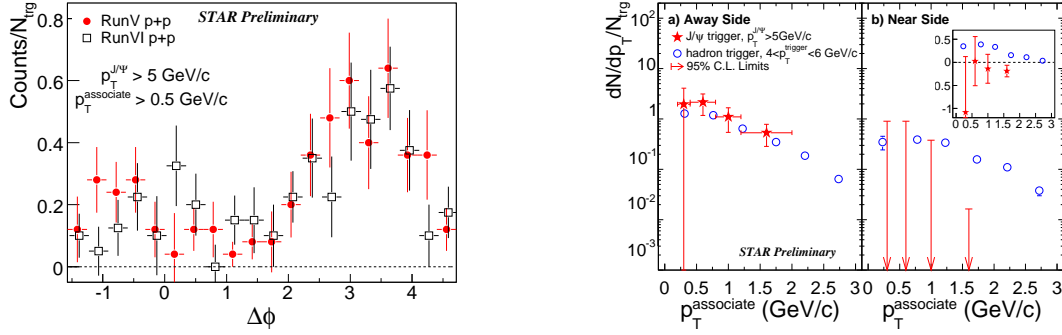
The invariant cross section of inclusive pion and proton production in high energy  $p + p$  collisions have been found to follow the  $x_T$  scaling law:  $E \frac{d^3\sigma}{dp^3} = \frac{g(x_T)}{\sqrt{s}^n}$ , where  $x_T = 2p_T/\sqrt{s}$ . The value of the power  $n$  depends on the quantum exchanged in the hard scattering and is related to the number of point-like constituents taking an active role in parton model. It reaches 8 in the case of a diquark scattering and reaches 4 in more basic scattering processes (as in QED). Figure 2 (middle) shows the  $x_T$  scaling of  $J/\psi$ , pion and proton. The power  $n$  was found to be  $6.5 \pm 0.8$  for pion and proton [5] and  $5.6 \pm 0.2$  for  $J/\psi$ , which indicates that the high  $p_T$   $J/\psi$  production mechanism is closer to parton-parton scattering.



**Figure 2.** Left:  $J/\psi$  invariant cross section as a function of  $p_T$  in  $p + p$  and Cu+Cu collisions at  $\sqrt{s_{NN}} = 200$  GeV. Errors shown are statistical only. Middle:  $x_T$  scaling of pions, protons and  $J/\psi$ s. The data from other measurements can be found in references [8, 9, 10, 12, 5, 2, 11]. Right:  $J/\psi$   $R_{AA}$  as a function of  $p_T$ . The dot-dashed line represents the fit by constant to all the data points at  $5 < p_T < 10$  GeV/c. The boxes on the right show the normalization uncertainty.

Figure 2 (*right*) shows the  $J/\psi$  nuclear modification factor  $R_{AA}$  as a function of  $p_T$  in 0-20% and 0-60% Cu+Cu from PHENIX [6] and STAR measurements.  $R_{AA}$  tends to increase from low to high  $p_T$ , although the error bars currently do not allow to draw strong conclusions. One can nevertheless do a combined fit to all the high-pt data and find that  $R_{AA} = 0.9 \pm 0.2$ . This result is in contrast to the expectation from AdS/CFT-based models [1] and from the Two-Component model [7] which predict a decreasing  $R_{AA}$  with increasing  $p_T$ . This result could indicate that other  $J/\psi$  production mechanisms such as virtual photons or formation time [13] play a role at high  $p_T$ .

With large S/B ratios, the  $J/\psi$ -hadron correlations were also measured in  $p + p$  collisions. Figure 3 (*left*) shows the azimuthal angle correlations between high  $p_T$   $J/\psi$  ( $p_T > 5$  GeV/c) and charged hadrons. No significant near side correlations were observed, which is in contrast to the dihadron correlation measurements [3]. Since the Monte Carlo simulation results show a strong near side correlation if the  $J/\psi$  is produced from  $B$ -meson decay, these results can be used to constrain the  $B$ -meson contribution to  $J/\psi$  production. Figure 3 (*right*) shows the associated charged hadron  $p_T$  distribution on the near side and away side with respect to  $J/\psi$  triggers and charged hadron triggers. On the away side, the yields of the associated charged hadrons with respect to both kinds of triggers are consistent with each other, which indicates that the hadrons on the away side of  $J/\psi$  triggers are from light quark or gluon fragmentation. On the near side, the associated charged hadron yields with respect to  $J/\psi$  triggers are significantly lower than those with respect to charged hadron triggers. This indicates that the  $B$ -meson is not a dominant contributor to the inclusive high  $p_T$   $J/\psi$ .



**Figure 3.** Left:  $J/\psi$ -hadron correlations after background subtraction in  $p + p$  collisions at  $\sqrt{s_{NN}} = 200$  GeV. Right: Associated charged hadron  $p_T$  distribution on the near and away side with respect to  $J/\psi$  triggers and charged hadron triggers.

### 3. Summary

We reported the STAR preliminary results of  $J/\psi$  spectra from 200 GeV  $p + p$  and Cu+Cu collisions at high  $p_T$  ( $5 < p_T < 14$  GeV/c) at mid-rapidity through the dielectron channel. The high  $p_T$   $J/\psi$  production was found to follow the  $x_T$  scaling with a beam energy dependent factor  $\sim \sqrt{s_{NN}}^{5.6 \pm 0.2}$ . The  $J/\psi$  nuclear modification factor  $R_{AA}$  in Cu+Cu increases from low to high  $p_T$  which challenges some models. The average of  $R_{AA}$  at  $p_T > 5$  GeV/c is  $0.9 \pm 0.2$ , consistent with no  $J/\psi$  suppression. It implies that high  $p_T$   $J/\psi$  may be produced from virtual photon or formed outside of the hot interaction region [13]. The  $J/\psi$ -hadron correlations were also discussed. We observed an absence of charged hadrons accompanying high  $p_T$   $J/\psi$  on the near side which indicates that the  $B$ -meson is not a dominant contributor to the inclusive high  $p_T$   $J/\psi$ .

### References

- [1] H. Liu, K. Rajagopal and U.A.Wiedemann, Phys. Rev. Lett. **98** (2007) 182301.
- [2] UA1 Collaboration, Phys. Lett. B **256** (1991) 112.
- [3] J. Adams, *et al.*, (STAR Collaboration), Phys. Rev. Lett. **95** (2005) 152301.
- [4] M. Anderson, *et al.*, Nucl. Instrum. Meth. A **499** (2003) 659; M. Beddo, *et al.*, Nucl. Instrum. Meth. A **499** (2003) 725; B.I. Abelev, *et al.*, (STAR Collaboration) Phys. Rev. Lett. **98** (2007) 192301.
- [5] J. Adams, *et al.* (STAR Collaboration), Phys. Lett. B **616**, (2005) 8; J. Adams, *et al.*, (STAR Collaboration), Phys. Lett. B **637** (2006) 161.
- [6] A.Adare, *et al.*, (PHENIX Collaboration), arXiv:0801.0220.
- [7] X. Zhao and R. Rapp, arXiv:0712.2407, private communication for Cu+Cu.
- [8] F. Abe, *et al.*, (CDF Collaboration), Phys. Rev. Lett. **69** (1992) 3704; D. Acosta *et al.*, (CDF Collaboration), Phys. Rev. D **71** (2005) 032001.
- [9] D. Abtreasyan, *et al.*, Phys. Rev. D **19** (1979) 764.
- [10] B.Alper, *et al.*, (British-Scandinavian Collaboration) Nucl. Phys. B **100** (1975) 237; C. Kourkouvelis, *et al.*, Phys. Lett. **91B** (1980) 481.
- [11] M. Banner, *et al.*, (UA2 Collaboration), Phys. Lett. B **115** (1982) 59.
- [12] A.Adare, *et al.*, (PHENIX Collaboration), Phys. Rev. Lett. **98** (2007), 232002.
- [13] F. Karsch and R. Petronzio, Phys. Lett. B **193** (1987), 105; J.P. Blaizot and J.Y. Ollitrault, Phys. Lett. B **199** (1987), 499